LA-UR-21-22686

Approved for public release; distribution is unlimited.

Title: A screening tool for assessing feasibility of re-using existing oil and gas wells for CCUS operations

Author(s): Pawar, Rajesh J.; Brunner, Logan; van der Valk, Kaj; van Bijsterveldt, Lonneke; Harp, Dylan Robert; Chen, Bailian; Cangemi, Laurent; Dudu, Alexandra-Constanta; Guy, Nicolas; Opedal, Nils; Williams, John

Intended for: 15th International Conference on Greenhouse Gas Control Technologies, GHGT-15, 2021-03-15 (Abu Dhabi, United Arab Emirates)

Issued: 2021-03-18

Disclaimer:
Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by Triad National Security, LLC for the National Nuclear Security Administration of U.S. Department of Energy under contract 89233218CNA000001. By approving this article, the publisher recognizes that the U.S. Government retains nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

15th International Conference on Greenhouse Gas Control Technologies, GHGT-15

15th 18th March 2021 Abu Dhabi, UAE

A screening tool for assessing feasibility of re-using existing oil and gas wells for CCUS operations

Rajesh Pawar[a]*, Logan Brunner[b], Kaj van der Valk[b], Lonneke van Bijsterveldt[b], Dylan Harp[a], Bailian Chen[a], Laurent Cangémi[c], Alexandra-Constanta Dudu[d], Nicolas Guy[c], Nils Opedal[e], John Williams[f]

[a]Los Alamos National Laboratory, MS T003, Los Alamos, NM, USA, 87545
[b]TNO Applied Geosciences, Princentonlaan 6, Utrecht, Netherlands, 3584CB
[c] IFP-EN, 1&4 avenue du Bois-Preau, Rueil-Malmaison, France, 92500
[d] National Institute for Research and Development on Marine Geologiy and Geo-ecology - GeoEcoMar, 23-25 Dimitire Onciul Street, Bucharest, Romania, RO-024053
[e] Sintef Industry, SP Andersens vei 15 B, Trondheim, Norway, 7030
[f] British Geological Survey, Environmental Science Centre, Keyworth, Nottingham, UK, NG12 5GG

Abstract

An increasing number of oil and gas fields around the world are coming to the end of their production lifetime and have been earmarked as potential targets for deploying large-scale carbon capture, utilization and storage (CCUS) operations. Existing oil and gas fields offer several advantages such as availability of existing infrastructure including wells as well as significant prior knowledge about the field through characterization and operational data. Existing wells at these fields could potentially be used as CO_2 injection wells, monitoring wells or production wells for pressure management. Re-using existing oil and gas infrastructure may be particularly crucial for offshore environments where new well development costs could otherwise be prohibitive. Prior to converting the existing oil and gas wells, feasibility of their use as part of a CO_2 storage operation will have to be evaluated while taking into consideration operational and safety requirements. Currently there are no standard approaches available for assessing the potential of converting existing wells for re-use in CCUS operations, and no public tools are available to aid the assessment process.
As part of the REX-CO_2 (Re-using EXisting wells for CO_2 storage operations) project funded by the ACT (Accelerating CCS Technologies) program, we have developed a workflow and a well screening tool that will aid in evaluating the feasibility of repurposing existing wells as CO_2 storage site wells. The workflow was informed by applicable standards such as ISO 27914, regulatory requirements such as the US-EPA's Class VI regulation and publicly available information from projects that have performed detailed assessments of using existing oil and gas wells for CO_2 storage, including the Peterhead, Kingsnorth and PORTHOS projects. Our assessment approach and the tool are designed to simultaneously save CO_2 storage projects resources and time by identifying existing infrastructure that is safe to re-use, while determining which wells must be remediated to ensure safe, long-term storage. The functionality of the tool will be evaluated and validated on six case study sites, one in each of the REX-CO_2 project's partner countries (France, the Netherlands, Norway, Romania, the UK, and the USA).

* Corresponding author. Tel.: +1-505-665-6929, *E-mail address:* rajesh@lanl.gov

Keywords: reuse, existing infrastructure, repurpose hydrocarbon wells, well integrity assessment

1. Introduction

Existing oil and gas fields are considered potential options for storing carbon dioxide (CO_2) as part of the Carbon Capture, Utilization & Storage (CCUS) technology. There are several advantages of using existing oil and gas fields including, extensive characterization information, knowledge of field through prior operations and availability of existing wells as well as other infrastructure. An existing well can be repurposed as a CO_2 injector, a water producer (for pressure management) or a monitoring well. Conversion of existing oil and gas wells to CO_2 storage wells can potentially result in cost savings, especially for offshore fields where costs for drilling and completing new wells can be significant.

An increasing number of oil and gas fields around the world are coming to the end of their production lifetime and are being earmarked as potential targets for deploying large-scale carbon capture, utilization and storage (CCUS) operations. Recently, multiple projects have explored the potential of converting existing oil and gas fields into CO_2 storage sites, demonstrating growing interest in re-using existing infrastructure. The Peterhead and Kingsnorth projects both aimed to convert existing hydrocarbon fields to CO_2 storage sites. The fields considered, the Goldeneye Gas Condensate Field [1] and Hewett Gas Field [2], had both either ceased production or were approaching their end of production life. The operators of these projects performed extensive technical assessments to ensure the feasibility, safety and practicality of converting and re-using the fields, consisting of assessments of existing infrastructure including the wells. Neither of these projects became operational due to lack of financing, however several detailed reports are publicly available which detail the evaluations used to assess the feasibility of re-using the existing wells. The PORTHOS consortium in the Netherlands is currently exploring the feasibility of converting the P18 gas field (offshore Netherlands), which is operated by TAQA, to a CO_2 storage site and Pale Blue Dot Energy in the UK is exploring the feasibility of using existing North Sea oil and gas infrastructure (namely pipelines) to develop a scalable CCS (Carbon Capture and Storage) system [3]. The technical assessments undertaken by these projects demonstrate that repurposing an existing oil and gas well as a CO_2 storage well is a complex process that includes multiple steps to ensure that the original well design is suitable for its intended purpose, and that the well can maintain its integrity under the conditions expected over the lifetime of the storage project.

Globally, the number of commercial-scale geologic CO_2 storage projects deployed to date are few, with limited global coverage and none have been deployed in depleted oil or gas fields while utilizing existing infrastructure. As a result, there are no established public practices for repurposing existing hydrocarbon wells to CO_2 storage wells or workflows to perform relevant assessments. In addition, there are no publicly available tools that can be utilized as part of the assessments.

The REX-CO_2 project (https://rex-co2.eu) is focused on responding to this need through the development of a publicly available screening tool. As part of the tool development process, we first developed a conceptual approach and a workflow by taking into account publicly available information from the Peterhead and Kingsnorth projects, design and integrity requirements of CO_2 storage wells and applicable standards. This paper provides an overview of the tool development process and relevant background.

2. Previous Industry Experience in Re-purposing Existing Hydrocarbon Wells to CO_2 Storage Wells

To date only a limited number of projects have considered using existing oil and gas fields for CO_2 storage. In response to the UK government's programme on CCS, the Peterhead and Kingsnorth projects were designed but neither were commissioned due to lack of funding. In addition to these two projects, in the Netherlands there is ongoing interest from the PORTHOS consortium to convert the P18 field into a CO_2 storage field. All of these projects have focused on re-using existing infrastructure in the North Sea given the costs associated with drilling new offshore wells. In France, TOTAL led in 2009-2013 the first French pilot to demonstrate the technical feasibility and reliability of an integrated CO2 capture, transportation, injection and storage scheme in the initially depleted gas field of Rousse.

2.1. Kingsnorth, Hewett Gas Field, UK

The Kingsnorth project included a plan to capture CO_2 from the Kingsnorth coal-fired power plant and store it in the depleted sandstone gas reservoir of the Hewett field [4] in the offshore UK. The project did not receive sufficient funding, and the Kingsnorth power plant finally closed in July 2015. The Hewett field was considered to have favourable characteristics for CO_2 storage. A primary objective for the redevelopment of the Hewett field was to limit the number of wells penetrating the caprock. As part of the project plan, existing wells, including 28 production wells and 5 exploration/appraisal wells, were assessed for re-use. All of the production wells were accessible raising the possibility of converting them to CO_2 injectors. However, following abandonment, it would not be possible to access the 5 exploration/appraisal wells. In evaluating the accessible wells, scarcity of data led to significant uncertainty regarding the likely integrity of the wells. The assessment led to the conclusion that the existing wells would not be suitable for re-use for CO_2 injection and storage given the high level of uncertainty around the condition and integrity of wells. Potential integrity issues arose because the wells were not originally designed for CO_2 storage operations and vital well construction details were poorly documented, particularly in the case of the older wells. Given that the well materials will be experiencing a CO_2-rich environment; corrosion, degradation of cement and potential presence of fractures as well as other fluid migration pathways in the cement were identified as factors that might potentially compromise long-term well integrity.

2.2. Peterhead, Goldeneye Gas Condensate Field, UK

The Peterhead CCS Project objective was to capture approximately 1 million tonnes CO_2 per year from the gas-fired power station at Peterhead, Aberdeenshire, over 15 years and store it in the offshore Goldeneye field [1]. The storage site, facilities and pipeline had previously been studied in substantial detail for the Longannet CCS project [5]. Goldeneye is a depleted gas condensate field with an estimated CO_2 storage capacity of a least 24 Mt. The assessment to determine re-use potential of existing wells included a review of the ability to ensure well integrity during and after injection of CO_2. The assessment was performed in two steps, first the existing wells in the area were assessed followed by an assessment of five proposed CO_2 storage wells. The five wells were originally completed using a similar approach and were suspended with deep-set downhole plugs after production was suspended. None of the production wells or the abandoned exploration and appraisal wells, were considered to have any major integrity issues [6]. Shell planned to use three of the Goldeneye production wells for CO_2 injection and one for monitoring, while the fifth well would be abandoned [7]. The well assessment included a detailed review of the condition and quality of the conductor and casings with focus on casing size, placement and loads and the suitability of the well materials in a CO_2-rich environment. The conclusion of the casing review was that the original design and choice of materials was sufficient for re-use. In addition to the casing, the cement quality, placement and properties were also reviewed, and it was concluded that the Portland cement used in the wells was suitable for a CO_2 injection environment. The project planned to run a cement bond log (CBL) during the workover operations to better assess the current integrity of the cement. The existing lower completion was found to be suitable for CO_2 service following an analysis of the materials (13Cr steel), corrosion, screen performance, and plugging of the screens and formation [7]. The existing upper completions and Christmas tree were deemed unsuitable for CO_2 service and would need to be modified.

2.3. PORTHOS, P18 Field, The Netherlands

In 2011, TNO conducted an independent storage assessment for application of offshore CCS close to Rotterdam, and identified the TAQA operated P18 cluster, just offshore of Rotterdam, as the best possible short-term option [8]. The total storage capacity was estimated to be 42.4 Mt CO_2 with an injection rate of ~2.4 Mt CO_2 per year. As part of the CATO program in the Netherlands, a more detailed assessment on the seven wells of the P18-2 block was conducted. The assessed well elements included the primary cement across the caprock, the production liner, the production casing, the wellhead, the production tubing (including jewelry, e.g. surface-controlled subsurface safety valve), the primary cement around the production casing, the production liner hanger and the production packer. The assessment concluded that the feasibility of CCS is primarily dependent on the accessibility and suitability of the wells. One of the wells in the P18 reservoir (P18-2) had been suspended with cement plugs and it was concluded that the well would have to be abandoned to ensure zonal isolation. The primary concern for the other wells was the questionable cement quality at the caprock based on the available CBL data requiring further detailed analysis. This could pose both short-term (during operational phase) and long-term integrity risk. Some of the proposed checks and remediations include confirming the packer load envelopes and material (elastomers, metals, pack-offs) compatibility to chemical and mechanical loads. In general, it was concluded that the existing wells can be accessed and therefore can be remediated to be re-used as CCS wells. It was suggested to keep some of the wells for monitoring purposes. A more detailed assessment as part of a permit application was conducted in 2019 and concluded that the maximum storage capacity in the P18 field is 33.8 Mt (combined P18-2 and P18-6 fields), with a final reservoir pressure just below the original gas reservoir pressure. Additionally, all reviewed wells have the potential to be re-used as CO_2 injectors. The wells would require mitigation measures (e.g. workover), or abandonment, appropriate options were suggested. The effect of injecting cold CO_2 on the cement interfaces was highlighted as a specific detail for well integrity [9].

The planning for the PORTHOS project is to make a final investment decision early 2022. Depending on the Final Investment Decision (FID), it is expected that the system will be constructed in 2022-2023 and operational by 2024.

2.4. Lacq-Rousse CO_2 Capture and Storage demonstration pilot, France

This pilot entails the conversion of an existing steam boiler into an oxy-fuel combustion unit, oxygen being used for combustion rather than air to obtain a more concentrated CO_2 stream easier to capture. Then, CO_2 stream was compressed and conveyed via pipeline to the Rousse depleted gas field, where it was injected into a deep carbonate reservoir. CO_2 injection started earlier 2010 as all the proper official authorizations have been given. The storage site of Rousse was a depleted gas field located in a rural and non-populated area, five kilometers to the South of the town of Pau and its suburbs (around 140,000 inhabitants). Stream was compressed and conveyed via pipeline to the Rousse depleted gas field, 29 kilometers away, where it was injected into a deep carbonate reservoir. From a geological point of view, the small depleted gas field of Rousse is a deep isolated Jurassic horst drapped and overlaid by a very thick Campanian to Eocene series of marls, shales and silts. Environmental monitoring performed after the injection phase confirms the absence of any leak from the CO_2 storage reservoir. After two and a half years of monitoring during the injection period and one-year preliminary baseline survey, the monitoring of the CCS Lacq French pilot has demonstrated that the CO_2 remains so far well confined within the reservoir. Thanks to the small quantity of CO_2 injected compared to the Rousse reservoir storage capacity, no reservoir or caprock loss of integrity was deplored as demonstrated by the micro-seismicity passive monitoring. Well integrity was also confirmed.

2.5. CO_2-EOR Fields, USA

While the previous 3 cases have focused on CCS projects, the other technology where existing hydrocarbon wells need to be repurposed for CO_2-rich environment is enhanced oil and gas recovery by CO_2 injection (CO_2-EOR) which has been performed for many years in the United States. Even though the primary objective for a CO_2-EOR well might not be for the *permanent* storage of CO_2, most of the requirements to ensure integrity of the well elements will be similar to those of permanent CO_2 storage. Such wells therefore offer a potential analogue for wells that might potentially be re-used in future CO2 storage operations. The numerous CO_2-EOR wells have led to an extensive know-how on dealing with well integrity, including a clear overview on suitable material for re-using existing wells for CO_2 storage. Many of the re-purposed wells were old (up to 50 years of age) and were affected by corrosion and/or erosion of the liner, production casing and surface casing [10]. Many of the wells were also previously used as water injectors with relatively large wash-outs resulting from water injection. A number of technologies were developed to help remediate these challenges and retrofit older wells for CO_2-EOR projects. These technologies will be potentially useful for CCS. Outside the experience on suitable material selection for CO_2-EOR wells, the engineering workflow and assessment of the CO_2-EOR wells followed those used for standard petroleum workovers which may be less relevant for development of re-use procedures for CCS.

3. Relevant Standards and CO_2 Storage Well Design

3.1. Standards & guidelines

Currently there is only one international standard and a single regulation exclusively developed for CO_2 storage well designs. The ISO 27914, developed for CO_2 capture, transport and geologic storage, includes a design standard for CO_2 storage wells [11]. The US Environmental Protection Agency's (EPA) Underground Injection Control (UIC) program's Class-VI well construction guidance identifies the requirements for techniques and materials for constructing CO_2 storage wells [12]. These have taken into consideration existing standards for oil and gas well construction including ISO 16530 (parts 1 and 2) [13, 14] and NORSOK D010 [15]. In addition, there are other existing standards and guidelines covering various aspects of well construction, completions, testing and operations that are relevant for this work including,

- Oil & Gas UK Well Integrity guidelines
- Oil & Gas UK Guidelines on qualification of materials for the abandonment of wells
- API/TR 10TR1 Cement sheath evaluation
- API RP 65-2 Isolating Potential Flow Zones during Well Construction
- API RP 90 Annular Casing Pressure Management
- NOGEPA Standard 41 Well Engineering and Construction Process
- NOGEPA Standard 45 Well Decommissioning
- NOGEPA Standard 51 Operational Barriers for Well Integrity
- Norwegian Oil and Gas Recommended Guidelines for Well Integrity

3.2. CO_2 storage well design

In order to assess the suitability of an existing oil and gas well as a potential CO_2 storage well, it is necessary to understand the design and functional requirements for a storage well. The primary objective of the standards and regulations mentioned above is to ensure that the wells are constructed such that they maintain integrity during their lifetime under the anticipated operational and post-injection conditions. Most of the standards, guidelines as well as regulations recommend the presence of multiple well barriers to ensure that in-situ fluids and in the case of CO_2 storage well, injected CO_2, are contained within the well to prevent unintended and uncontrolled flow of fluids within or out of a well or surrounding environment. A well barrier is a combination of one or several well barrier elements (WBEs). The objectives of a well barrier are to:

- Withstand the maximum anticipated combined loads to which it can be subjected.
- Function as intended under the expected pressure, temperature, chemical (CO_2-rich, HC-rich, high-salinity) and mechanical stress conditions throughout its entire life cycle.
- Prevent uncontrolled and un-intended flow of injected CO_2 and in-situ fluids (HC and/or brine) within the wellbore or to the external environment.

Examples of WBEs include casing, cement, caprock, tubing, subsurface safety valve (SSSV), etc. Note that different barrier elements have to be connected together to form a well barrier envelope. As a minimum requirement, two barriers are recommended at all times: a primary barrier and a secondary barrier (Fig. 1). In certain cases, more than two barriers could be required or present. The primary barrier is the first barrier and is in direct contact with reservoir fluids at reservoir pressures. The secondary barrier is not directly exposed to the reservoir fluids and pressures and provides redundancy in case of failure of primary barrier elements. It is the secondary line of defence against unintended, uncontrolled fluid flow from the wellbore to the environment.

4. Well Re-use Assessment Workflow

Currently there are no publicly available standard workflows for assessing the feasibility of re-using existing hydrocarbon wells for CO_2 storage. We utilized the state-of-the-art well design and combined knowledge from previous assessments mentioned earlier to develop a conceptual workflow to fill this need. Our workflow is designed

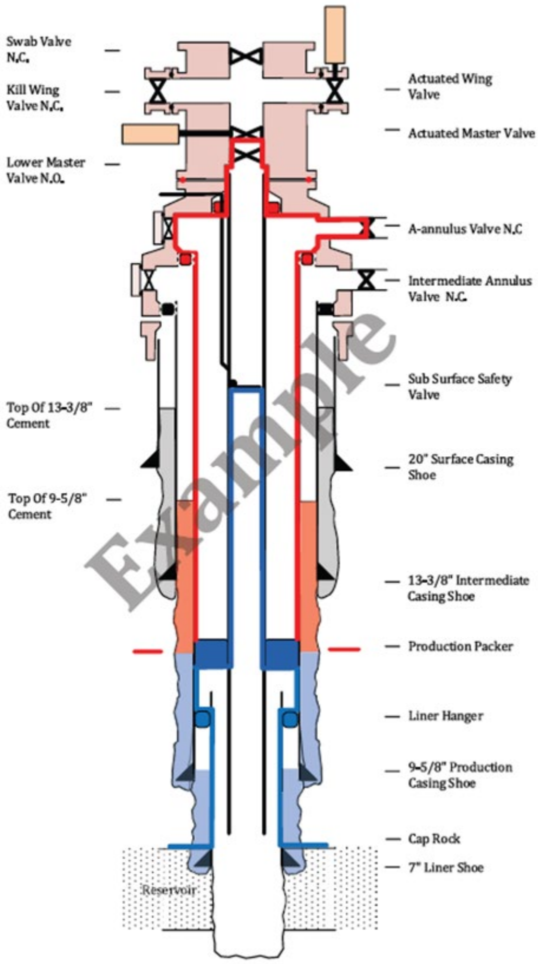

Fig. 1. An example wellbore barrier schematic from ISO 16530 [13]. The primary barrier is indicated by blue lines & secondary barrier is indicated by red lines.

to guide a stakeholder through the multiple steps of the technical assessment to check suitability of an existing well against functional and integrity-related requirements of a CO_2 storage well. Our assessment framework primarily includes assessment of well design and well suitability. The main objective of well design assessment is to ensure that the well can maintain its integrity under expected operational and environmental conditions over its lifetime and includes well integrity assessment, out of zone injection risk assessment, well structural integrity assessment and well material compatibility assessment.

Our assessment is qualitative and is designed to be used as part of a pre-feasibility assessment. We expect that these pre-feasibility assessments will typically be followed by detailed techno-economic evaluations such as those performed for the Goldeneye, Hewett and PORTHOS wells as well as development of risk management approaches. We developed decision trees that include the various steps corresponding to different evaluations that will be required. The various steps of the decision trees are designed as queries with yes or no responses and are intended to be used by people with access to information about the wells and the means to assess the information. A brief description of the decision trees follows.

4.1. Well integrity assessment

The well integrity assessment is designed to assess the integrity and effectiveness of the well barrier elements over a well's intended lifetime. As mentioned earlier, the current standards and regulations for well integrity recommend the presence of two barriers, a primary and a secondary barrier (Fig. 1). The two barriers differ mainly through the combination of WBEs which make up the individual barriers. The decision tree for well integrity was developed assuming a well has two barriers. Even though there are two separate barriers, the assessment steps are similar and are essentially repeated through application to different WBEs that make up the individual barriers. The first step in the decision tree is verification of primary WBEs including SSSV, tubing, tubing hanger, casing or liner, primary caprock, cement across primary caprock, packer and other jewelry that may exist and be directly contacted by the pressure and/or injected CO_2. Any indication of sustained pressure and/or fluid leakage in the relevant annuli is verified. Following verification of the primary well barrier, the integrity of the secondary barrier is verified through assessment of its WBEs including the wellhead, Christmas tree, casing and/or liner, liner hanger, cement, secondary barriers, secondary impermeable formations, etc. Additionally, any indication of sustained pressure and/or fluid leakage in the annuli behind the secondary barrier envelope is verified.

4.2. Out of zone injection risk assessment

The out of zone injection risks primarily arise due to potential unwanted migration of CO_2 and in-situ reservoir fluids (brine and/or hydrocarbons) out of the storage reservoir through pathways behind the primary casing as demonstrated in Fig.2. The pathways could be pre-existing or could be created due to casing shoe failure, poor cement job quality, loss of cement sealing, failure of caprock or inadequate sealing of overlaps. The decision tree is designed with queries to verify:

- Proper cementing job by confirming sufficient use of cement and adequate cementing to create a sufficient number of barriers to isolate the injection zone.
- Cement has integrity as demonstrated through appropriate cement evaluation logs.
- The maximum anticipated pressure at casing shoe depth is lower than the formation strength or fracturing pressure at that depth.
- Casing shoe and formation have integrity as verified through Formation Integrity Testing (FIT) or Leak-Off Testing (LOT).
- Casing and/or liners do not show evidence of corrosion.
- Any overlaps (e.g. liner laps) are properly sealed.
- The production packer was installed at proper depth with sufficient formation strength.

4.3. Material compatibility assessment

The material compatibility assessment is focused on assessing the ability of the well materials to withstand the chemical conditions that result due to exposure to CO_2 in addition to the temperature changes that may occur during injection. The steps are designed to verify that well materials can withstand a CO_2-rich environment (e.g. 13Cr-L80 or higher sour grade steel) as well as if the presence of H_2S is expected. The well should be designed to offer protection against galvanic corrosion as recommended in ISO 27914 [11] or similar. The well components such as elastomers and pack-offs can withstand the CO_2-rich corrosive conditions. In addition to chemical changes a CO_2 injection well may also experience extremely low temperatures, especially at the start of injection (or restart of injection if injection has been stopped for various reasons) due to the Joule-Thompson effect, especially with low reservoir pressures. The assessment steps include verification that the well materials are designed to withstand the low temperatures and resulting thermal stresses.

4.4. Structural integrity assessment

The assessment of structural integrity of the well is designed by taking into consideration the recommendations described in ISO 16530 [13, 14] & NORSOK D010 [15] standards as well as the Oil & Gas UK guidelines [16]. The

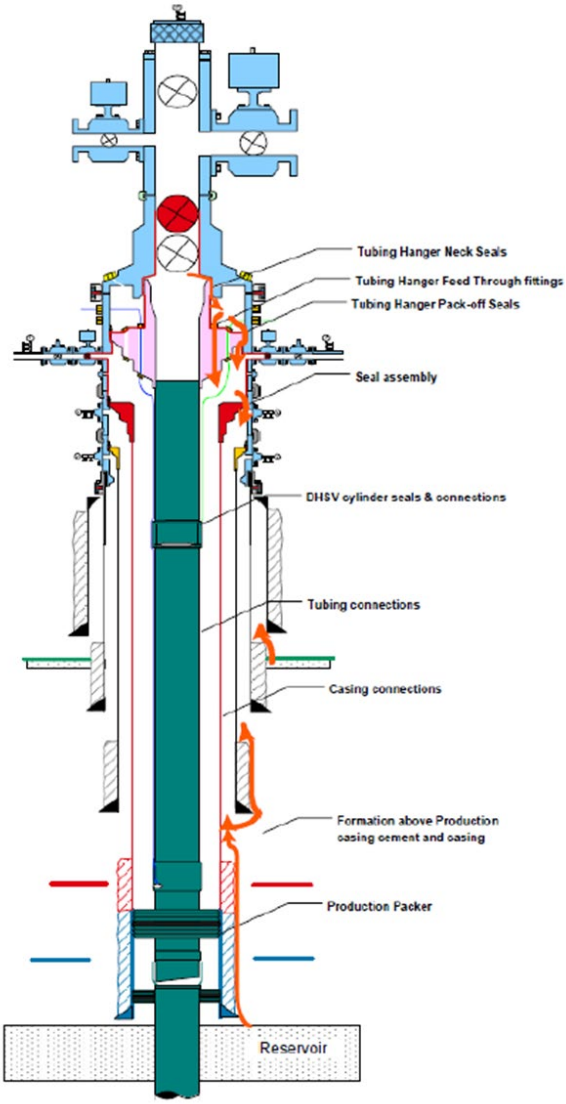

Fig. 2. Out of zone injection conceptual diagram [17].

structural integrity of a well is typically provided by the conductor casing, surface casing and the wellhead. The presence and type of these components will vary based on whether the well is onshore or offshore and will also vary with well design. The potential failure modes for structural components can include metal corrosion, metal fatigue due to cyclic loads, degradation of soil strength, squeezing due to moving formations such as salt, etc. The assessment for structural integrity includes verification that the primary structural components will have sufficient strength to ensure the structural integrity of the well over its expected lifetime under the anticipated operational conditions.

4.5. Cement integrity predictions

In addition to the above-mentioned assessments related to well design and construction, we also developed an approach to determine the probability of failure of integrity in the cement and primary caprock barriers and in case of failure resulting amount of CO_2 leakage. We take a two-step approach: first, we determine the probability of developing leakage pathways at the cement/caprock interface due to debonding of cement by looking at the mean aperture of resulting micro-annuli. Next, we utilize the mean aperture and storage reservoir pressure to estimate the time-dependent CO_2 leakage rate and cumulative leakage over the lifetime of the project. For both these steps, we developed and used fast, predictive reduced order models (ROM) [18]. For the debonding predictions we developed a ROM using results from an extensive set of geomechanical simulations (~ 4000 simulation runs) performed by TNO [19, 20]. The geomechanical simulations were performed using the finite element analysis software DIANA FEA and simulated evolution of geomechanical conditions in the cement/caprock environment behind wellbore casing as a result of changing pressure/stress conditions due to CO_2 injection through the wellbore. The DIANA FEA simulation predictions included aperture of micro-annuli, if any were formed, within the wellbore/caprock/cement environment. The ROM linked the predicted micro-annuli aperture to the input parameters, including Young's modulus of cement, Poisson's ratio of cement, tensile strength of cement-rock interface, and temperature difference across tubing and caprock. For calculating CO_2 leakage rate through cement with micro-annuli, we utilize the ROM for predicting CO_2 leakage through cemented wellbores developed as part the National Risk Assessment Partnership (NRAP) project [21]. The output of the micro-annuli aperture ROM is used to calculate an effective permeability of cement which is one of the inputs for the cemented wellbore ROM.

5. Well Screening Tool

The decision trees and the models for cement integrity prediction were used to develop a well screening tool. As stated earlier the tool is designed to help any informed user to go through a step-by-step evaluation process associated with determining feasibility of re-using an existing hydrocarbon well. The screening tool is designed to be interactive with an ability to provide inputs needed as part of the assessment. The decision trees include queries associated with each step to which a user can provide a "yes" or "no" response. Typically, a positive (yes) response indicates that the well meets certain requirement and a negative (no) response indicates that it does not, but this is not the case for all questions. In order to respond to the different queries, a user is expected to have access to relevant information or data for the well such as its design, completion, status of well components, results of tests performed for verifying its integrity, etc. In the case that the relevant information is not available, the user can provide "don't know" or "missing data" response.

The responses to all queries for each of the assessments (well integrity, risk of out of zone injection, material compatibility, and structural integrity) are recorded and are collectively used to determine if:

1. The well in its current state meets the requirements for each of the assessments and can be used for CO_2 storage application without any modification.
2. The well in its current state may not meet the requirements for each of the assessments but can be used for CO_2 storage application with some modifications.
3. The well in its current state may not meet the requirements for each of the assessments and its use for CO_2 storage application will require significant modifications.

At the end of the assessment a user is provided with results indicating one of the above. We require that in order for a well to be re-used in its current state (without any remediation or workover) it has to meet all the requirements for each of the four well design-related assessments. If a well fails one or more of the four, the result indicates that the well can either be used for a CO_2 storage application with some modifications in order to satisfy all the requirements, or would require significant modifications in order to make it usable. The tool is designed to provide a user with a list of the issues that need to be addressed to meet the requirements. In addition, the user is recommended to perform a detailed techno-economic evaluation as part of the overall feasibility evaluation. In the case that a user does not have relevant data or information and responds with the "don't know" or "missing data" option, the user is provided with a recommendation that critical information needed for assessment is missing along with a list of information that the user should collect to provide with a proper evaluation. In certain cases missing data may result in a decision of not re-using the well rather than collecting additional information.

The well screening tool was developed using the same software framework that has been used to develop NRAP-Open-IAM, NRAP's Integrated Assessment Model for geologic CO_2 storage risk assessment. Fig. 3 shows the general setup for well screening tool while Fig. 4 shows the initial dashboard for the tool.

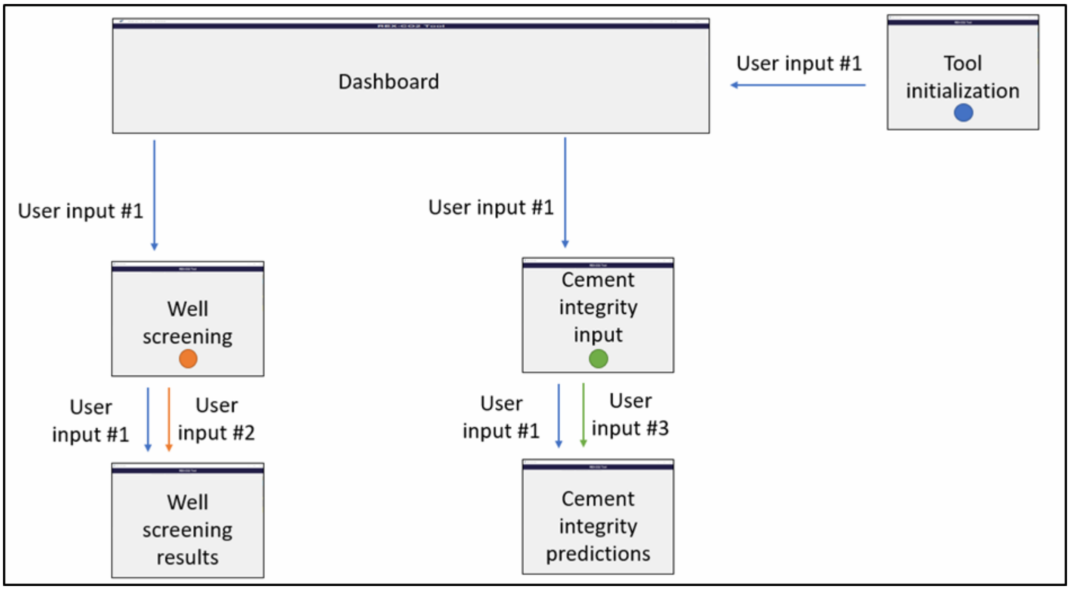

Fig. 3. General structure for the REX-CO_2 well screening tool.

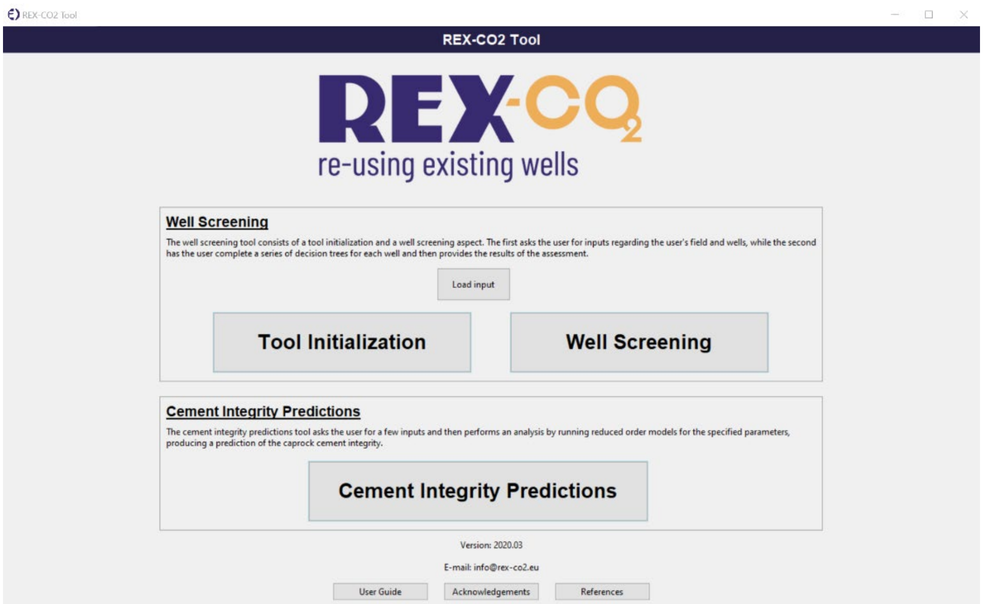

Fig. 4. The initial dashboard for REX-CO_2 well screening tool.

We have developed an initial version of the tool and have tested it using a number of varied case studies. We are using results of these tests to update the tool and will be applying the updated tool to multiple case studies for fields from the REX-CO_2 consortium partner countries.

6. Summary

An increasing number of oil and gas fields around the world are coming to the end of their production lifetime and are being earmarked as potential targets for deploying large-scale carbon capture, utilization and storage (CCUS) operations. There are multiple advantages of using existing oil and gas fields including extensive characterization information, knowledge of field through prior operations and availability of existing wells as well as other infrastructure. Conversion of existing oil and gas wells to CO_2 storage wells can potentially result in cost savings, especially for offshore fields where the cost of drilling and completing new wells can be significant. Currently, there are no established practices for repurposing existing hydrocarbon wells to CO_2 storage wells or workflows to perform relevant assessments. In addition, there are no publicly available tools that can be utilized as part of the assessments. As part of the REX-CO_2 project we have developed a workflow that can be used to assess the re-use potential of an existing oil and gas well as a CO_2 storage well. Our workflow is based on evaluating an existing well against the requirements to ensure the well can maintain its integrity under the conditions it will experience throughout its life. The workflow was developed by taking into account the requirements for a CO_2 storage well as defined in ISO 27914 standard as well as US-EPA's Class-VI regulations, which were specifically developed for CO_2 storage wells, together with the ISO 16530 and NORSOK D010 standards. We have developed a well screening tool based on the workflow. The well screening tool will be tested and applied to multiple case studies from different countries. We plan to make the screening tool publicly available to the wider CCS community and other interested stakeholder through the REX-CO_2 project.

Acknowledgements

The project REX-CO_2 is funded through the ACT programme (Accelerating CCS Technologies, Horizon2020 Project No. 299681). Financial contributions made from ADEME (FR); RVO (NL); Gassnova and RCN (NO); UEFISCDI (RO); BEIS, NERC, and EPSRC (UK); and US-DOE (USA) are gratefully acknowledged. The contents of this publication reflect only the author's view and do not necessarily reflect the opinion of the funding agencies.

References

[1] Shell, 2016. FEED summary report for full CCS chain. Peterhead CCS Project, K02-11.122.
[2] E.ON, 2011. Kingsnorth carbon dioxide capture and storage demonstration project key knowledge reference book.
[3] Acorn, 2019. Accelerating CCS Technologies: Acorn project, D20 Final Report, February 2019. https://www.actacorn.eu/about-act-acorn/act-acorn
[4] Tilling GM, Manning GE. The Rejuvenation of Hewett Field. Offshore Technology Conference, 1-4 May, Houston, Texas. Offshore Technology Conference. OTC-6118-MS. 1989.
[5] Scottish Power CCS Consortium. SP-SP 6.0 – RT015 FEED Close Out Report. UK Carbon Capture and Storage Demonstration Competition. April 2011.
[6] Shell Well Integrity Assessment Report. Peterhead CCS Project Doc No. PCCS-05-PT-ZW-7180-00004, Revision K02, DECC Ref 11.113. 2014.
[7] Shell Technical Specification. Peterhead CCS Project Doc No. PCCS-05-PT-ZW-7770-00001 , Revision K03, DECC Ref No 11.099. 2015.
[8] Neele F, Hofstee C, Dillen M, Nepveu M. Independent storage assessment of off shore CO2 storage options for Rotterdam – summary report, TNO report TNO-060-UT-2011-00809, 2011 (http://www.globalccsinsti tute.com/publications/independent-storage-assessment-offshore-co2-storage-options-rotterdam-summary-report).
[9] Neele F., Wildenborg T, Geel K, Loeve D, Peters L, Kahrobaei S, Candela T, Koenen M, Hopman P, van der Valk K, Orlic B, Vandeweijer V. CO_2 storage feasibility in the P18-2 depleted gas field. TNO Report 2019 R11635.
[10] Folger, LK, Guillot SN. A case study of the development of the sundown slaughter unit CO2 flood Hockley County, Texas. Permian Basin oil and gas recovery conference 27-29 March, Midland, Texas. SPE-35189-MS. 1996.
[11] ISO. Carbon dioxide capture, transportation and geological storage – geological storage, ISO 27914:2017.
[12] US EPA. Geologic sequestration of carbon dioxide: Underground injection control (UIC) program Class VI well construction guidance. 2012.
[13] ISO. Petroleum and natural gas industries – Well integrity Part 1: Life cycle governance. ISO 16530-1:2017.
[14] ISO. Petroleum and natural gas industries – Well integrity Part 2: Well integrity for the operational phase. ISO 16530-2:2013.
[15] Standards Norway. NORSOK Standard D-010. Well Integrity in drilling and well operations. Rev 3. 2004.
[16] Oil & Gas UK. Well Integrity guidelines. Issue 1, July 2012.
[17] IEAGHG. Re-Use of Oil & Gas Facilities for CO_2 Transport and Storage. 2018/06, July 2018.
[18] Chen B, Harp D, Brunner L, van Bijsterveldt L, van der Valk K, Pawar, R A novel machine learning approach for reduced-order model development with imbalanced data. Virtual poster, AGU Fall Meeting 2020. http://agu2020fallmeeting-agu.ipostersessions.com/Default.aspx?s=3C-86-3F-B9-EC-C9-F7-BE-E4-1B-99-DF-88-A4-2A-0F
[19] Orlic B, Chitu A, Brunner L, Koenen M, Wolllenweber J, Schreppers GJ. Numerical investigations of cement interface debonding for assessing well integrity risks. 52nd US Rock Mechanics / Geomechanics Symposium (ARMA). Seattle, Washington, USA. 2018; ARMA 18-1298.

[20] Brunner L., Koenen M, Orlic B, Wollenweber J. A Bayesian Belief Network to Assess Risk of CO_2 Leakage Through Wellbores. In 14th Greenhouse Gas Control Technologies Conference Melbourne 21-26 October 2018 (GHGT-14), Available at SSRN: https://ssrn.com/abstract=3365825 or http://dx.doi.org/10.2139/ssrn.3365825.
[21] Harp DR, Pawar RJ, Carey JW, Gable CW. Reduced order models for transient CO_2 and brine leakage along abandoned wellbores from geologic carbon sequestration reservoirs. Int. J. Greenh. Gas Control. 2016;45:150-62.